THE SUN AND STARS[1]

IV.

Changes of Wave-Length

THE spectroscope not only enables us to determine the chemical constitution of the spots, but it allows us, by the alteration in the refrangibility in the various lines, to determine the rates of motion at which each of the vapours is descending. The hydrogen lines are not thickened as the other lines are in the spots; they are at times thickened on one side only, that is to say, they are what is called contorted. The line suddenly changes its position in the spectrum towards the less refrangible part of the spectrum, which is the red end. Now the amount of change towards the red along the spectrum measures exactly for us the rate of downrush, and we learn generally that the hydrogen is rushing down at the rate of 30 or 40 miles a second. These changes are associated with brightenings of the line, which we shall have to refer to afterwards.

The fact that we get those extraordinary inversions above referred to of the various lines in the spectrum of a substance is simply explained by the assumption that the substance is an exceedingly complicated thing that is broken up into simpler things at the temperature of the sun, and that some of these things exist in some sunspots, while other constituents exist in others. The changes of wave-length come to the support of this argument. If a chemical element is one thing, it cannot be doing two different things at the same time; if its vapour in a spot is homogeneous, one set of lines cannot tell us that it is going up and another that it is going down; but that is exactly what the sun does tell us.

Those results, like the previous ones relating to the inversions, of course are simply and sufficiently explained by the assumption that we are not dealing in any one vapour with one set of molecules only, but that we are really dealing with various constituent molecules, and that some of the molecules may be in one stage of simplicity, some of them may be in another; some may be at rest, while the others may be in very violent motion. These observations of the relative movements of the vapours have been made at different times and in different parts of the spectrum. We get, in all of them, contorted lines, showing us that a particular vapour is moving; while other lines in the spectrum of the same substance indicate that there is no movement whatever in the vapour in that particular spot.

This problem, however, has a very great difficulty connected with it, because it will be readily understood that the slit of the spectroscope has to be kept absolutely on the same part of the sun. It would not do, it would not be fair, for instance, to have the slit of the spectroscope resting on one part of the sun, and then make an observation of a line of any particular substance indicating motion, and then to let it, even by accident, travel on to another part of the spot and find out that the next line of the same substance indicates rest. The answer to that would be—You are dealing with two different parts of the spot. The observations must be made contemporaneously. I may tell you parenthetically that we have a new instrument now which I think will help us very considerably in these inquiries. This is a spectroscope having a diffraction-grating with 17,000 lines to the inch, which gives us, therefore, a very considerable dispersion. What has been done has been to cut the grating in two. If the two parts of the grating are absolutely in the same plane, of course the whole grating will be receiving the light which comes from the sun direct into the spectroscope, and will send a definite part of the spectrum to the eye; both parts of the grating then will be building up a spectrum of the same part of the sun, and will give us the result in the same part of the spectrum. But now that we have split the grating we have the power of altering the inclination of one half of it, while the other half remains rigidly in its first position. Hence we can make any part of the spectrum overlap any other part, and in this way, instead of being limited to observations of parts of the spectrum sufficiently close to each other to be visible in the same field of view, we can compare lines in the red part of the spectrum thrown to the eye by one part of the grating with lines in the blue part of the spectrum thrown by the other. In this way we are able to make comparisons from one end of the spectrum to the other, when there is no doubt whatever that the slit is lying on the same part of the spot; this will be an enormous safeguard against error.

We have taken several photographs of the spectra of sunspots at Kensington; nearly all of them indicate that two lines of calcium in the ultra-violet spectrum—two lines it is difficult to see with the eye—are always bright, while all the rest remain dark. Another important fact is that in addition to the downrush, the velocity of which has been already stated as something like 40 miles a second on the average; there are in the neighbourhood of the spots, in consequence of the disturbances produced, violent movements of the lower parts of the solar atmosphere which we should call *winds;* that is to say, instead of being up and down they are really horizontal along the surface of the sun. Now 140 miles a second is no uncommon velocity for these winds, and we may imagine, therefore, that the heated gases of the photosphere, and the cooler gases of the spots, are very often arranged in layers. When this is so it is easy by the appearance of the widened absorption-lines to determine the existence of a hotter layer above or between cooler ones. We get what is called a double reversal of the lines.

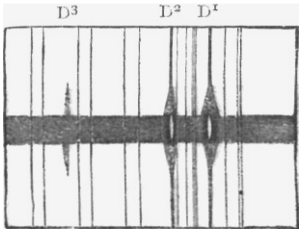

FIG. 8.—Spectrum showing the double reversal of the D lines due to hotter sodium vapour overlying cooler sodium vapour in the sunspot.

Prof. Young, of America, has been fortunate enough to detect one case with, I think, no less than three strata of incandescent sodium vapour inter-layered between three strata of relatively cool sodium vapour. When we wish to consider the phenomena of spots in their entirety therefore, we must not consider the downrush on the photosphere merely, but must also bear in mind the lateral currents which are produced by the disturbances it has set going.

Conclusions

I will now state the conclusions at which we have arrived touching sunspots by means of the work which I have brought before you. You will see they are all of them important with regard to the structure of the lower part of the solar atmosphere.

(1) The spot spectra are very unlike the ordinary Fraunhofer spectrum.

(2) We get as much inversion of lines in the case of one element as we do between the lines of different elements; by which I mean that the lines of nickel, say, are just as much varied in different spots as the lines of iron, nickel, and calcium would be in spots in which the proportions of these substances very greatly varied.

(3) Very few lines indeed are strongly affected at the same time. A great many lines of the same substance are affected of course besides those included in the twelve which have been recorded at South Kensington as most widened every day; but a small number of the lines altogether are affected in this manner.

(4) There is a change depending on what I shall afterwards have to refer to as the sunspot period; that is to say, day after day, month after month, year after year, the lines of any particular substance thickened in the spots are not the same. In fact towards the end of the year 1881 (we began our observations in the year 1879) the iron lines which were strongly affected at first died out altogether.

(5) Many of the lines seen in the spots are lines seen at low temperatures, and none of them are brightened or intensified when we pass from the temperature of the electric arc to that of the electric spark.

(6) In the first 200 spots observed 101 lines were recorded which have never been mapped in any laboratory; that is to say, they do not correspond with lines seen in the emission-spectrum of any substance with which we are familiar.

(7) Many of the lines widened are new solar lines; that is to say, they are not visible among the Fraunhofer lines at all.

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[1] A Course of Lectures to Working Men delivered by J. Norman Lockyer, F.R.S., at the Museum of Practical Geology. Revised from shorthand notes. Continued from p. 472.

(8) Many of the lines most frequently seen widened are common to two or more substances when low dispersions are employed.

The Chromosphere

In what has gone before we have been chiefly occupied with a discussion of the various chemical materials which we can trace in those cavities in the photosphere which we call spots. We have now to begin the consideration of the chemical materials which can be traced in that solar envelope which lies immediately over the photosphere, I mean the chromosphere: so that eventually we may endeavour to make a comparison between the chemical materials in the spots and in the chromosphere, which are supposed to lie, and which in fact really do lie, at about the same height in the solar atmosphere, with, however, the enormous difference that we know the spots are caused by the descent of materials coming down from above, and we do not know at present that that is true with regard to the substances in the chomosphere.

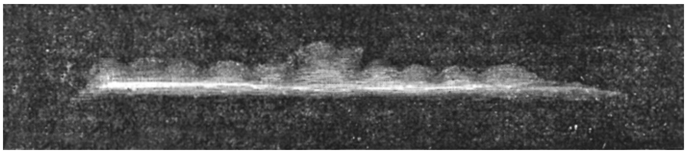
FIG. 9.—The chromosphere—billowy.

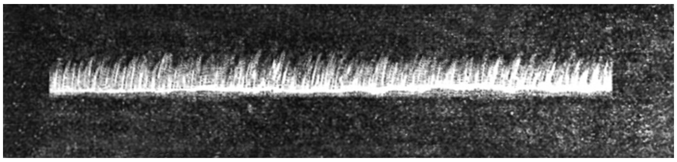
FIG. 10—The chromosphere—spikey

Now, the chromosphere we will take roughly, as it varies in height from year to year, and from latitude to latitude, to be between 5000 and 10,000 miles high. It is not only bright at the bottom—so bright, very often, that in eclipses, when the bottom is seen, observers imagine that the sun has reappeared—but it is exquisitely coloured at the top, the colours very often being scarlet, crimson, green, yellow, and so on. As ordinarily observed, the simple chromosphere varies very considerably.

The first distinction that we have to draw is that in some parts its surface seems to be billowy, in other parts prickly; some have likened the latter condition to grass, some have likened it to flames; but at all events the distinction is that in many cases it is serrated, and in other cases its saw-like appearance gives way to a much softer billowy outline. These spikes, or grass blades, or whatever we may liken them to, really want very much more study than they have received, for the reason that if they are studied they will give us some ideas on a very important subject. What one wants to know now, I think, almost more than anything else, is the direction in which the currents on the surface of the sun flow; a careful study of the direction of these flames may eventually give us some very material aid in that direction.

The chromosphere, taken most generally, is chemically a sea of hydrogen, *plus* something that we do not know. Above the photospheric level, and for some distance above it, the chief substance which we see in the sun is incandescent hydrogen gas. Now, on our earth we have at the present moment no free hydrogen whatever; all the hydrogen we have is locked up in combination with other substances. At the same time it is fair that I should point out that hydrogen is a very considerable constituent of water, which seems to play the same part with regard to the solid crust of the earth as the chromosphere plays with regard to that shell of the sun which we call the photosphere.

Its Spectrum

What one sees when one immerses the slit of the spectroscope in an image of the sun so that only half the slit is covered by the disk is shown in the accompanying diagram of a part of the spectrum. You must imagine that the slit is, as I said before, half on the sun, and half off it. We have the Fraunhofer lines in the red part of the general spectrum of the sun. We see what the spectroscope picks up outside the sun altogether. It picks up one line, and one line only, coincident with a dark line in the ordinary solar spectrum. That we know is a line due to hydrogen. In the chromosphere, this line appears as a bright line because it has not behind it waves of greater energy, and therefore it gives us its own light. You understand in a moment that the height or length of the line depends upon the depth of what I have ventured to call the sea of hydrogen. If this sea is shallow, the line will be short; if the sea is deeper, the line will be longer.

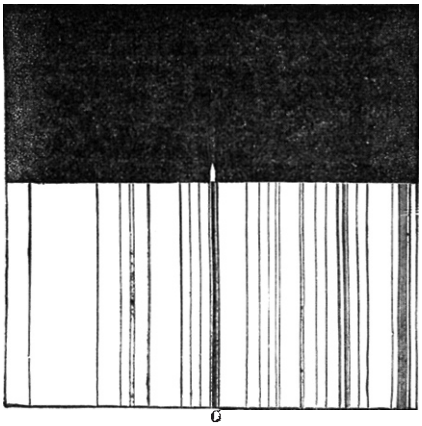

FIG. 11.—One of the hydrogen lines of the chromosphere.

I have said that it is a sea of hydrogen. It is not, however, merely a sea of hydrogen. Of the spectrum of five lines generally thus seen, one of them we do not understand at all. This line is in the orange part of the spectrum, and is called D^3, because it is near to D^1 and D^2; it is a line, I am sorry to say, which has never yet been seen in any terrestrial laboratory.

This, then, is the most simple and the most constant spectrum of the chromosphere.

It has already been pointed out that if the old view that the various substances were assorted in the solar atmosphere according to their atomic weights were correct, then we should have in the chromosphere a spectrum very rich indeed in the lines of the substances with which we are perfectly familiar, and especially in the lines of those substances which are of high atomic weight. The condition which it reveals is just about as opposite as can be imagined.

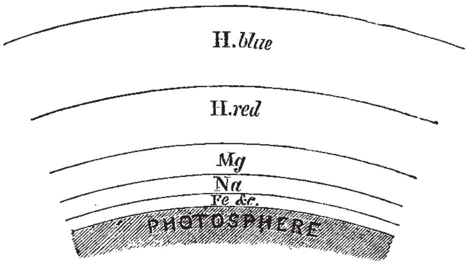

FIG. 12.—Early hypothesis of the arrangement of materials in the Sun's atmosphere. H = hydrogen; Mg = Magnesium; Na = sodium; Fe, &c. = iron and the other elements of high atomic weight.

Amongst those who have most closely examined this chromosphere is Prof. Respighi. From his observations we gather that its brilliancy is exceedingly variable in different parts of the sun; that as a rule it is greatest near the spots; that its height, or its depth, if we like that expression better, is greatest at the poles; that it is always shallow near the spots.

Injections

Occasionally the level of this sea over a very large region is gradually, peacefully, and quietly raised, and when that happens we get short lines—shorter than those of hydrogen—of other substances, and the indications afforded by the observations show us that this welling up is due to the intrusion of other vapours. There seems to be a gradual distillation from out the photosphere, or a gradual heating of slowly falling material, and these lines appear delicately over large regions, pushing up the upper level of the sea of hydrogen, so that the spectrum of the portion of the atmosphere near the photosphere gets richer and richer; we get, in fact, layers of different substances.

I give a table showing the lines which have been thus most constantly seen, in addition to the five lines above referred to. The wave-lengths given are from Thalèn and Ångström.

Table showing Lines of Chromosphere

1869		Hydrogen	All lines	
		D^3		
		1474 (5315·9)	Unknown	
		b^1 b^2 b^4	Magnesium	3 out of 7 (T)
		b^3	Nickel	1 ,, 34
		D^1 D^2	Sodium	2 ,, 8
		4933·4 4899·3	Barium	2 ,, 26
	⌽ ⌽	4923·1 5017·6	Iron	2 ,, 460 (Å)
		5275		
		5233·6 5179·9 4921·3 5014·8 bright	Unknown	
After 1869				
	 ⌽	*f* 4471 4924·5 B—C B—*a*	Unknown	
	⌽	5019	Titanium	1 out of 201 (T)
		H K	Calcium	2 ,, 74

Some remarks on this table may be permitted. The first new line is called in spectroscopic language 1474, for the reason that when this work was begun the only maps at the disposal of investigators were those made with great care by Prof. Kirchhoff. He gave a scale of such a nature that this particular line fell at 1474 on that scale. Since then these artificial scales have been discarded in favour of the natural one, which is given us by the actual wave-lengths of light. In this the actual number of that line is 5315·9, which represents the actual wave-length in ten-millionths of a millimetre of that particular quality of light. After this we observe three lines of magnesium—only 3 out of 7. Next, a line of nickel, one only, however, out of 34. Then two lines of sodium. We might naturally expect to get all the 8 lines of sodium, but we do not. Then come two lines of barium out of 26, and so on. For the rest, we see that almost all the other lines have origins which are absolutely unknown, that is to say, we never get them in our terrestrial laboratories, and never, therefore, are able to match the bright lines in this envelope of the sun which we are now discussing with any chemical substance. In the year 1871 we got other lines added to those first observed, because, as we shall see by and by, the sun was then more active, and this activity resulted in the addition of new lines, all of them, however, as you see, absolutely unknown to us, except one which represents a line which we observe in the spectrum of titanium; but in that case we get one line out of 201 in exactly the same way as we get two only of iron out of 460.

The latest constant addition to the lines of this envelope are H and K, two lines so named among the Fraunhofer lines, which we have already seen brightened in spots. Here, again, as in the case of iron and titanium, we only get two lines out of a large number.

Now, over certain reaches of the sun these injections, as we may call them, have been seen to last for a fortnight, quite independent of any spot in the locality, and while the rest of the periphery of the sun has been more or less tranquil.

Here is a drawing showing two gentle wellings up of the chromosphere to which I have referred. The distance from the horizontal line shows the depth of the strata indicated by the lengths of the various lines. The stratum which reaches highest up has a spectrum containing a certain line of magnesium. The next, which is shallower, consists of a substance about which we know nothing, except that its line is called "1474." Then, again, we get other shallower strata giving us still shorter lines. These, again, are of unknown origin. The lower we go the deeper does the mystery become.

The next point it is important to notice is that none of the lines which we have in the table as representing the spectrum of the chromosphere, and those special lines to which reference is now being made as representing the usual commencement of an injection into the chromosphere below, are among those which are widened in the spots. That is an important point to make, and we shall have to refer to it again by and by.

The announcement that iron existed in the sun, an announcement made by Kirchhoff a good many years ago now, was made because he found, or said he found, that all the lines which we see in our laboratories agreed absolutely, both in position and relative strength, with the lines which can be seen in the spectrum of the sun. If that reasoning is good for the general spectrum of the sun, and if we assume it to be equally good for the spectrum of this special part of the sun—viz. the chromosphere—you will see that if we accept Kirchhoff's line of argument we have no right whatever to say that any of the chemical substances that we are familiar with here exist in this part of the sun, which, as I have told you, is the very hottest part to which we can direct any inquiries.

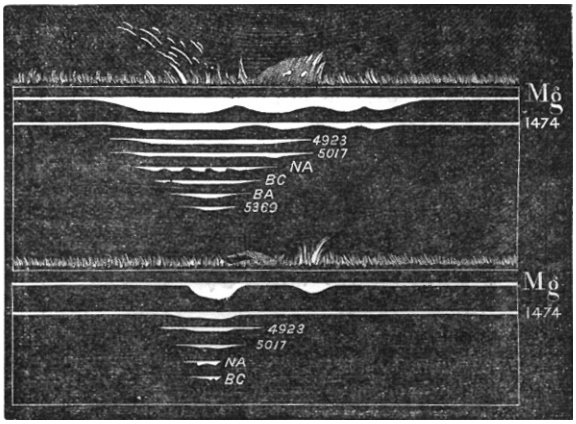

FIG. 13.—Wellings up of vapours.

So much, then, for a general statement with regard to the chemical nature of the chromosphere.

The Chromosphere Disturbed

These injections are at times the first beginnings of an apparent disturbance of the temperature equilibrium, or at all events of the chemical equilibrium of the chromosphere, for, soon after they make their appearance, we frequently get another indication that there is a disturbance going on by the formation of what is called a prominence—a *quiet* prominence; and when we are familiar with those forms of prominences the distinction between a quiet prominence and one of the other kind is a very decided one.

As a rule they need not be very high. By very high I mean 40,000 miles. And also these quiet prominences may last for a very long time. Many of them resemble trees. I was fortunate enough to be one of the early observers of these exquisite forms which one never gets tired of looking at, and the first time I saw one I wrote down in my note-book that the chromosphere and prominences in that place reminded me of an English hedge-row with luxuriant elms. The lower part of the chromosphere, of course, represented the hedge, and the prominences the elms. The simile of a hedge with trees in it was not at all a bad one, but some years afterwards I found a very much better one, and one perhaps nearer the truth of Nature. It was my duty in the year 1878 to go to America to look at an eclipse. I crossed the Atlantic in the high summer, and we naturally had to pass through a considerable amount of fog. We were three days in a dense fog, and one of the delightful things about that fog was this, that one day we were steaming through an opening, and we saw the edge of the fog, which was apparently upright and solid, about a mile off, and we coasted along it. I found that that fog was fed by what I at once called fog-spouts. You know what water-spouts are, and you have all seen drawings of them, and the drawings of water-spouts that I have seen represent the reality very well. If you imagine a bank of fog about 50 or 60 feet high filled with little fog-spouts, you get exactly what I then saw, and you get exactly what one often sees in these quiet prominences on the sun, and I really believe that what I and others have likened to the trunks of trees may be really somewhat akin to these fog-spouts, with the enormous difference, however, that we are dealing with water and aqueous vapour in one case, and with the photosphere of the sun and incandescent hydrogen gas in the other.

These quiet prominences, when we come to examine them with the spectroscope, seem to be built up entirely of hydrogen. When I say quiet you must understand that the word is a relative one. I have seen a quiet prominence as big as a dozen earths born and die in an hour. That is not at all an uncommon thing. And there are several facts which indicate that when such a prominence disappears, it does not mean that the stuff disappears; it means that it changes its state, that is to say, it chiefly changes its temperature. We can understand that these prominences, if they are excessively hot, will be very much more brilliant than if they are cool. If, therefore, they cool more or less suddenly, we may lose sight of them, but it may be that the hydrogen is there just the same, although it is no longer in a condition to radiate so much heat, and therefore light, to us. There is also evidence that these prominences are really, the quietest of them, due to up-rushes of gas from below.

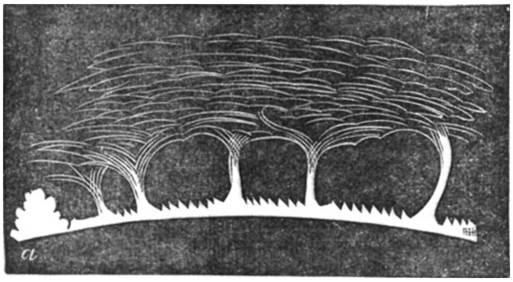

FIG. 14.—Tree-like prominences.

When we watch the growth of a prominence it expands from below, close to the photosphere. First the prominence is of small height, then it gets higher and generally broader, and after a certain time we may see a kind of cloud formed at the top of it, but we never see the prominence coming down, as we have imagined the cooler materials of the sun must come down, to form a spot.

It happens very rarely indeed that any very large horizontal motion is indicated in such prominences as these. Drawings of prominences indicate very clearly the extraordinarily curious forms which these masses, which consist chiefly or entirely of hydrogen gas in the sun's atmosphere, put on.

J. NORMAN LOCKYER

(*To be continued.*)

SOCIETIES AND ACADEMIES

LONDON

Geological Society, February 19.—Annual General Meeting.—Prof. T. G. Bonney, F.R.S., President, in the chair.—The Secretary read the Reports of the Council and of the Library and Museum Committee for the year 1885. In the former the Council stated that they had the pleasure of congratulating the Society upon an improvement in the state of its affairs, both from a financial point of view and on account of an increase in the number of Fellows. The number of Fellows elected during the year was 54, and the total accession amounted to 51; while the losses by death, resignation, &c., amounted to 46, making an increase of 5 in the number of Fellows. The number of contributing Fellows was increased by 15. The balance-sheet showed an excess of income over expenditure during the year of 347*l.* 18*s.* 2*d.* The Council's Report further announced the awards of the various medals and of the proceeds of the donation funds in the gift of the Society. In handing the Wollaston Gold Medal to Mr. Warington W. Smyth, F.R.S., for transmission to Prof. A. L. O. Des Cloizeaux, the President addressed him as follows:—Mr. Warington Smyth,—In the absence, which we much regret, of Prof. Des Cloizeaux, I must request you to transmit to him this medal. Geology is the child of two parents—mineralogy and biology. If we look to the latter to bid the dry bones and buried relics of organisms once more live, we appeal to the former to disclose the nature and constitution of the earth's framework whereon they flourished. It is therefore only just that our Society should seek opportunities of acknowledging the aid which we receive from mineralogists; and it would be difficult to find one on whom this Wollaston Medal could be more fitly conferred than on Prof. Des Cloizeaux. To enumerate the papers which he has written would be a formidable task; they numbered 141 so long as fourteen years ago; what, then, must be the present total? I may, however, point in passing to his admirable "Manuel de Minéralogie," and allude, as more directly bearing on the work of this Society, to his papers on the classification of hyperites and euphotides, on the geysers of Iceland, on the action of heat upon the position of the optic axes in a mineral, and the numerous memoirs on the distinction of minerals by their optical properties, especially those relating to microcline, and to other species of feldspar, of the importance of which students of microscopic petrology are daily more sensible. I esteem it a great honour to be the means of carrying into effect the award of the Council by placing in your hands, to be transmitted to Prof. Des Cloizeaux, the Wollaston Medal, founded "to promote researches concerning the mineral structure of the earth."—The President then presented the balance of the proceeds of the Wollaston Donation Fund to Mr. J. Starkie Gardner, F.G.S., and addressed him as follows:—Mr. Starkie Gardner,—The small number of students and the paucity of memoirs seems to indicate that fossil botany is one of those subjects of which the difficulties repel rather than fascinate the neophyte. If these are in some respects less formidable in the plant-remains of the earlier Tertiary period, if, in studying them, recent research throws some light on fossil botany, yet the practical difficulties of obtaining, developing, and preserving specimens are so great that no little ardour and patience are demanded from one who devotes himself to the subject. For years this has been your special work: after thoroughly exploring the flora of the Eocene Tertiaries on the coast of Hampshire and in the Isle of Wight, you are now, and have for some time been, engaged in communicating to us the fruits of your labours through the medium of the Palæontographical Society, thereby earning the thanks of students. Your researches also of late years have been extended to Antrim, Mull, and even Iceland, and their results cannot fail to be of the highest interest in regard to the age of these floras, and their relation to those which occur in the Hampshire district. In recognition of past, and in aid of future, work the Council has awarded to you the balance of the Wollaston Fund, which I have much pleasure in handing to you.—The President next presented the Murchison Medal to Mr. William Whitaker, B.A., F.G.S., and addressed him as follows:—Mr. William Whitaker,—To many members of the Geological Survey of Great Britain since the date of its constitution we are indebted for work freely done—beyond the sphere of their more strictly professional duties. Its chiefs, from the days of Sir H. de la Beche to the present distinguished Director-General, Dr. A. Geikie, have been among the most valued contributors to our *Journal*, and have enriched geological literature by their longer writings; while among its other members, few have done more than yourself in following the example of its leaders. On the present occasion I will only allude to the various memoirs of the Geological Survey, especially that on the London Basin, in which you have taken so large and important a share, and will dwell rather on your contributions to our own *Journal* and to other publications. Your papers on the western end of the London Basin and on the Lower London Tertiaries of Kent deserve to be ranked with the classic memoirs of Prestwich as elucidating the geology of what I may call the Home District; and your last contribution to its deep-seated geology is still too fresh in our memories to need more than a mention. We do not forget your varied and valuable contributions to the *Geological Magazine*, especially those on the Red Chalk of Norfolk, on the water-supply from the Chalk, on the formation of the Chesil Bank (written jointly with Mr. Bristow), a paper, as it seems to me, of remarkable suggestiveness; and last, but by no means least, on sub-aërial denudation, in which, as remarked by the late Mr. C. Darwin, you had "the good fortune to bring conviction to the minds" of your fellow-workers by means of "a single memoir." We are also greatly indebted to you for your labours